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Contribution to the experimental study of the concrete behavior in its climatic environment.

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Abstract

Several studies have demonstrated the aggressive effect of very high temperatures, exceeding 100 ° C, on the behavior of concrete. However, the effect of local service temperatures remains significant, even very important, if we consider the safety margins provided during the sizing of pieces in the warm regions and their severe climatic conditions of the setting and hardening. In this context, the data on the behavior of the concretes at service temperatures are necessary to predict the safety of the buildings and constructions in various regions. The main objective of this paper is to determine the sensibility of the concrete to its climatic environment, during the period of service in the Saharan regions. It has been shown, by using three different compositions of concrete based on local materials, that the performance of concrete fall considerably with the increase of the temperature until 60 ° C. A thermal enclosure was conceived; the evolutions of the strength are presented and compared with those obtained for the reference results at 20°C temperature. The consequences on the durability and the reliability of structures in these regions are important, which appeals to the necessity in a consideration the risks caused by geo-climatic conditions during the design of structures.

Keywords: concrete, temperature, strength , climatic, service.

1. Introduction

Concrete is a construction material that is widely used in many different structures including houses, commercial, roadways, bridges, underground structures, and waterfront structures. These structures are dynamics systems subjected to continuous changes in temperature. More importantly, parts of these

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structures are exposed to extreme environmental conditions such as with bridge piers, dams, and waterfront structures. They experience variations in the tidal zone, hence continuous changes in the temperature. Temperature variations affect the strains induced in concrete structures and mechanical properties of the concrete as well. Concrete properties are usually determinated at standard laboratories conditions where air is at 20°C. There has been enormous research on the curing of concrete during extreme cold and dry conditions, warm and humid conditions, as well as extreme hot and dry conditions [4,5]. the environmental conditions, when concrete is poured and cured have an impact on the proprieties of the final product. Therefore, in extreme weather conditions such as extreme cold or hot, construction may be delayed until climate conditions improve unless precautions are taken for concrete curing. For example, normal concrete can be poured in sub-freezing temperatures if the surfaces are heated and the concrete is covered. Normal concrete can also be poured in hot dry conditions if the surface is wetted periodically and covered. The concern is what happens after the concrete has cured. There is little research on the mechanical proprieties of cured concrete at outside temperature conditions. It would be impractical, due to high-energy costs, to heat or cool the concrete surface during extreme weather conditions to room temperature.

Previous studies indicated that concrete exhibits change in its compressive strength as environmental conditions change. Therefore, to design a long lasting concrete structure, it is necessary for the structural designer to know the range of the mechanical properties of concrete corresponding to temperature levels expected to be present at the construction site so that appropriate factors can be considered. In general the more that is know about material properties the more parameters can be used in determining a safety factor. A safety factor compensates for unknown factors. It ensures that the strength of the material is stronger than the stress applied to it and strain is within an acceptable range. The effect of temperature and the resulting uncertainty in concrete material properties are often ignored or more likely unknown. To offset this lack of knowledge, a large safety factor is currently used. This can cause several problems. If the safety factor is too large, a structure will cost more than needed. If the safety factor is too small, a structure could fail. In order to minimize the risk of failure and high cost it is important for the structural engineer to incorporate temperature into a model.

A significant amount of research work has been conducted on the curing of concrete at different temperatures. However, there is little literature on temperature effects of cured concrete and most of that is at very high temperatures [3,4], in order to evaluate the strength of concrete in a fire. There is also a great amount of information on the freezing and thawing of water on concrete as well as creep and thermal mass. It is important to eliminate cracks when pouring concrete. Cracks allow water to steep inside and then when the temperature drops below 0°C the water freezes. Water unlike most molecular actually expands when it goes from the liquid to solid phase. The molecular expansion is stronger than what the concrete can resist, thus it will enlarge any existing cracks. In the review, there is some focus on the freezing and thawing of the ground, effect on concrete, as well as creep and thermal stresses on cured concrete. Temperature effects on curing concrete were also looked into, through the main topic consists of how different temperature effect cured concrete properties.

In this context, the work which we have undertaken is essentially experimental, and had for objective to examine the effect of temperatures variations on the strength of concrete that has been completely cured. The research also aimed to show the sensitivity of the concrete in his climatic environment, with use of a thermal enclosure. In order to achieve the overall objective, supportive have been identified as:

To design and build an environmentally controlled enclosure that can fit the standard concrete specimen and properly fit under the testing compressive machine to facilitate testing the concrete at different temperatures.

To measure the strength of concrete at various temperatures. Additionally, all the aforementioned strength was measured with different compositions while curing in order to assess the gain in each strength as the concrete natures.

Nomenclature

SK	sand of Kalloum
SH	Sand of Hassi 20
SR	Sand of Rosfa taeiba

2. Experimental program

Towards the northern part of Africa, is located the country of Algeria while sharing a vast coastline along the Mediterranean Sea, a comprehensive analysis of the geography of Algeria, gives us an insight into the different geographical features of the country. Algeria has a climate that varies considerably from north to south, the coastal area has Mediterranean climate, while the highlands south of the coast have hot summers and cold winters with low rainfall, major are the changes between day and night temperatures. Further south, lies the Sahara desert, thus defining the sector that interests us in this study. In the huge desertic area of Algerian Sahara, the climate is extremely arid, with seasonal and daily temperature ranges from -10°C, to while maximum temperatures sometimes exceeding 50°C. This paper presents the results of compressive-test specimens that were subjected during 24 hours to cold temperature (-15 and -10°C) and to high temperatures such as 40, 50 and 60 °C.

2.1. Materials properties

Table 1. Properties of the materials used in this study.

properties	sands		
	SK	SH	SR
characteristic	0/5	0/5	0/5
Sand equivalent (%)	95.60	66.10	36.16
absolute density	2.63	2.62	5.50
bulk density	1.70	1.60	4.30
Sand fineness modulus	5.15	3.16	4.23
nature	Limestone		siliceous limestone
form	Rolled		Crushed
properties	Gravel G		
characteristic	3/8		
absolute density	2.63		

bulk density	1.40
Flattening coefficient	15.50
Los Angeles coefficient	22.94
Micro Deval coefficient	10.62
absorption coefficient	0.45
nature	Limestone
form	crushed

For the preparation of various concretes, drinking water was used. Globally its own specific characteristics are conforming to the used specifications of water according to the standard NF P18-303.

The cement CPJ-CEM II / A 42.5 (NA 442-200) was used, its chemical and mineralogical composition are presented in Table 2.

Table 2. Cement composition

Chemical composition (%)					
SiO2	Al2O3	FeO3	CaO	MgO	CaO libre
22.28	5.50	4.65	65	0.98	1.80
Mineralogical composition (%)					
C3S	C2S	C3A	C4AF		
64	18	8	10		

Three concrete mixtures were used. Alls mixtures used were with CPJ-CEM II / A 42.5 cement and gravel (G). (SK) sand was used as the aggregate in mix1, while sands SH and SR were used in mix Bo(HJ) and Bo(RJ) respectively (Table 3).

Table 3. Concrete compositions.

materials	Quantity (Kg/m3)		
	Bo(KJ)	Bo(HJ)	Bo(RJ)
water	0/5	0/5	0/5
cement	350	350	350
gravel	1015,83	1132.6	1010.3
sand	719.00	629.93	673.95

The concretes studied here are classics, its means that their compositions, implementation, mode of conservation are current in civil engineering. In this work we have chosen to consider a constant workability of concrete and not the ratio for water to cement. However, the sand crushed of SR which was used contains 5 to 7% of smaller particles than 80 microns, which are increasing, as well as, the water requirement of concrete. That's why we have varied the ratio for water to cement from 0.5 to 0.705. Standard concrete specimen molds were prepared according to ASTM standard C470. Each mold thoroughly cleaned before any concrete was poured. Special care was taken while removing the concrete specimens from their molds. It is important to treat all of the specimens in the same manner to ensure that they all cure at equal rates. The concrete specimens were cured according to ASTM standard C192. Proper concrete curing is the most important step when making a concrete structure, in this case concrete prismatic specimens. When pouring freshly mixed concrete into the concrete molds, they were filled to the third at first. The concrete was then compacted to ensure all of air was allowed to escape. The concrete was compacted with the use of a compacting table; the procedure was repeated twice filling the mold with concrete. The top surface was then finished. The concrete was allowed to cure for 28 days in as close to ideal conditions as possible before compression and tension tests were completed at varying temperatures. Three specimens were consumed during each compression end tensile test. There were periodic tests before the final test on day 28 to make sure the concrete cured properly. A total of 200 specimens were cast, cured and tested. After 28 days, the specimens were stored in the thermal enclosure during 24 hours at different temperature (-15,-10, 10, 20, 30, 40, 50 and 60 °C) in order to evaluate the short term thermal effect on the strength of concrete.

2.2. Temperature controlled enclosure

In order to strength testing of cured concrete at various temperature in a lab environment, a system was required that would control the temperature of the concrete being tested. A thermal enclosure was needed in order to stabilize the temperature of the concrete specimens inside the compressive testing machine during the crushing test. This presented a number of challenges because concrete specimens have to be maintained at proper temperature throughout the duration of the test. The enclosure was required to be large enough to allow concrete specimens to properly fit inside, and the enclosure had to properly fit under the testing machine in the laboratory, to facilitate testing the concrete at different temperatures. The thermal enclosure designed for this experiment has a modular structure that can be mounted in the compressive testing machine, Figure 1.

(a) (b)

Figure 1. The hydraulic compressive press
(a) without thermal enclosure (b) with thermal enclosure

The walls of the thermal chamber define the interior volume and their role is to limit the exchange of heat between inside and outside. In order to achieve this, the thermal insulation of the side walls is obtained by superposition of several distinct layers. The chamber was constructed of thick plywood and lined internally with insulation. There was a rubber gasket in the chamber removable lid. In order to avoid the risk of accidents during the manipulation, the thermal enclosure was thermally and electrically isolated. The insulation contributes to the protection of the machine against the heat, and also prevents the damaging of the compression press and minimizes thermal losses, and avoids the heat transfer by decreasing losses.

3. Results and discussions

Figure 4 shows the experimental compression-test results of the thermal effects on the average strength of different concretes studied. Note that the average values of the three recorded strengths were used in the graphs presented in these Figure. We can distinguish mainly three consecutive phases in the evolution of compressive strength:

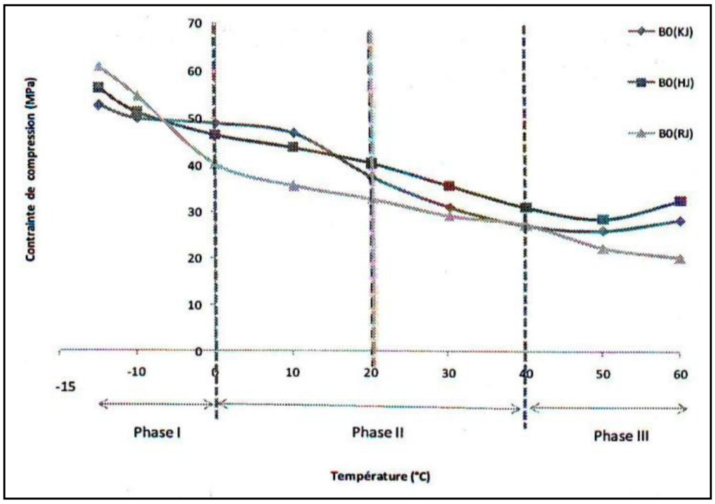

Figure 3. Effects of temperature on compressive strength

-Phase I: in this first phase (-15°C to 0° C), it can be observed that at a temperature of -15°C, the average compressive strengths are increased by 85.35 %, 40.41% and 39.47 % respectively for the B0(RJ) , B0(HJ) and B0(KJ), when compared to the reference results at 20°C temperature.

-Phase II: for temperatures included between 0°C and 10°C, it can be noted that the curves keep the same position registered in the previous domain (-10°C until 0°C). On the other hand, for temperatures situated between 10°C and 40°C, the concrete B0(HJ) presents good resistances, this implies that it is less influenced in this range of temperature.

-Phase III: This phase can be divided in two parts. In the first part (from 40°C up 50°C), the strength for all concrete studies, increases gradually with significant temperature increasing. However, in the second part, the average strengths are creased, for the specimens that were exposed to temperature of 50 °C and 60 °C, recorded only by the both compositions B0(KJ) and B0(HJ) . For cons, the composition B0(RJ) presents a strong decrease of resistance reaching values lower than 21 MPa, when this concrete is heated to 60°C. At this stage of temperature, the compressive strength relieved, for the concrete B0(HJ), is greater than 30 MPa.

In general, the overall results indicate that the strength decreases as temperature increased. The concrete specimens are stronger at lower temperatures and weaker at higher temperatures.

The increase of strength at low temperature can be attributed to a formation of the ice in hydrated cement paste. Since, the freezing point of water is even less than the size pores are small, so that the absorbed water freezes at low temperatures [5]. Such as the ice can resist to the constraints, contrary that the water which it replaces, the frozen concrete has an extreme low effective porosity and therefore high strength. If the concrete is not exposed to lower temperatures, the pores are empty, so as the increase of the strength is low. According to Korhonen, concrete's largest vulnerability lies in its resistance to freezing and thawing. Concrete contain a complex structure of pores that from as it cures. The report focuses on the cement component of the concrete since this is were the pores form. Water react with cement, a process called hydration, to form calcium silicate hydrate (C-S-H gel) and calcium hydroxide (CH). C-S-H gel contributes to concrete's strength by bending the aggregate together with van der Waals forces. More capillary pores as formed with concrete made with high water to cement ratios. Water will freeze in three pores causing damage to the concrete. Consequently, cold temperatures have negative impacts on cured concrete as well. Water unlike most molecules actually expands when it solidifies. Freezing and thawing can damage concrete even if there no cracks large enough for liquid water molecule to steep through and without rain.

Note that when a concrete is subjected to a very high temperature, it does not mean that the entire mass of concrete will be at that temperature. The time variable is very important when conducting tests on the stress of concrete. When there is a large temperature variation between the outer most shell and the core of specimen, large thermal gradients and stress will develop.

At high temperatures, the results indicate that the strength of concrete increases as temperature falls. These reductions are attributed to the degradation of the concrete. Note that although the reductions are significant at 50 and 60 °C, this decrease can be attributed to the evaporation of free water. According to different authors, when the concrete is exposed to high temperatures, its microstructure is subjected physical and chemical to changes along the heating causing dehydration of the cement gel (CSH). All changes start with the evaporation of free water and the decomposition of ettringite in the temperature range 30 ° C to 90 ° C [6]. All phenomena are developed at the microscopic scale, resulting in a macroscopic scale, by a progressive damage of the material and a significant risk of thermal instability [1]. According to [8] various tests that were reviewed the concrete loses up to 50% of its compressive strength for every 66°C rise in temperature. In this case concrete lost 40% of its strength for 50°C temperature rise.

4. Conclusion

In fact, the concrete structures will always be susceptible to thermal action [Favre and al 97]: for functional reasons (structure normally undergoing high gradients in service) climate (daily and seasonal variation), accidental (fire, shock techniques), climatic (diurnal and seasonal variation), accidental (fire, technical shock), in the end particular (partial or local demolition by thermal process).Consequently, the concrete is still in service at different temperatures. This range of temperature is expanded in countries with warm climate, at the same time with very cold regions. We can have situations in which it is exposed to very high temperatures, sometimes exceeding 50°C, for the Saharan climate. It seems now essential to know the effect of temperature on the variation in material properties. Therefore, temperatures play as large role in affecting the properties of concrete. Higher temperatures will yield lower concrete strength in compression. Both heat and cold poses dangers to cured concrete. Heat reduces the strength of concrete due to several reasons including spelling. The cold indirectly causes cracks to form in the concrete, which reduces its strength. At the molecular level, assuming no moisture presence in the concrete, heat will always reduces the concrete strength, while the cold will increases the concrete strength. This is due to the fact that the molecules are packed more closely together when the concrete is cold.

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